8TH SOUTHERN AFRICA
REGIONAL CONFERENCE

14 - 17 NOVEMBER 2017

**Electricity Supply to Africa and Developing Economies –
Challenges and Opportunities**

Technology solutions and innovations for developing economies

Employment of various strategies in Eskom to optimize the management of transformer life cycle and making the transformers part of the smart grid solution

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SUMMARY

Asset management is generally defined as a systematic process of deploying, operating, maintaining, upgrading, and disposing of assets cost-effectively. In recent times asset management has grown to be the most discussed topic and it is one of the key strategies to keep businesses efficacious. For Eskom, as a power utility, this refers mainly to the management of its plant assets employed in power stations and substations, simply referred hereafter as a substation. One of the key and very expensive equipment in a substation is a power transformer. The power transformer is used to transform power from one voltage level to another, and hence it links two or more voltage levels in a substation.

Alongside the topic of asset management is the smart grid topic. From various definitions of smart substation and smart grids, there are key words that tend to be common on those definitions; and these are; a smarter way of doing things, safety (of environment, people, and assets), ability to adjust, data acquisition, infrastructure availability, communication, and some others. Smart grids require smart substations that are built with smart equipment. Transformers are again viewed as one of the key areas in moving towards smart substations.

Eskom employs a number of transformers and has a great need to address both of the mentioned topics. Transformer engineers in Eskom have a great task of continually finding ways to better manage the life of both the new and the aged fleet of transformers and to make the same fleet to align with the requirements of substation visualization towards smart grid environment, while they remain cost-effective.

This is achieved by utilizing various technologies that can at least allow the engineers to prolong life expectancy and time between maintenance intervals of transformers, reduce maintenance requirements, enhance the performance of the asset, reduce operational and safety risks, or reduce human dependency.

The implementation of these technologies is approached as an integrated and coordinated exercise based on a clear technology roadmap, condition monitoring philosophy, maintenance philosophy, and other critical asset management principles. Eskom, with regard to transformers, has established all these philosophies and these are being updated from time to time as more learning and and further experience are being gained.

This paper reflects on the current experience or journey of Eskom from the various aspects of this migration and highlights the planned way forward.

KEYWORDS

Power transformer, technology, online condition monitoring, maintenance, asset health, substation visualization, smart grid/substation.

1. INTRODUCTION

Eskom is operating about 6 000 power transformers rated at 2.5MVA and above. This number includes transformers installed in power stations and in transmission and distribution substations, but it excludes the power reactors. This fleet of transformers is made up of both the modern and the ancient designs. The technologies and the engineering know how built into these units is obviously of a wide range. This is because the engineering understanding, the technology, the end user requirements, and the applicable standards have evolved over the years. The average age of the fleet is about 28 years against the expected life of 35 to 40 years. A particular distribution of the fleet age is demonstrated in figure 1 below using the fleet in the Eskom transmission network.

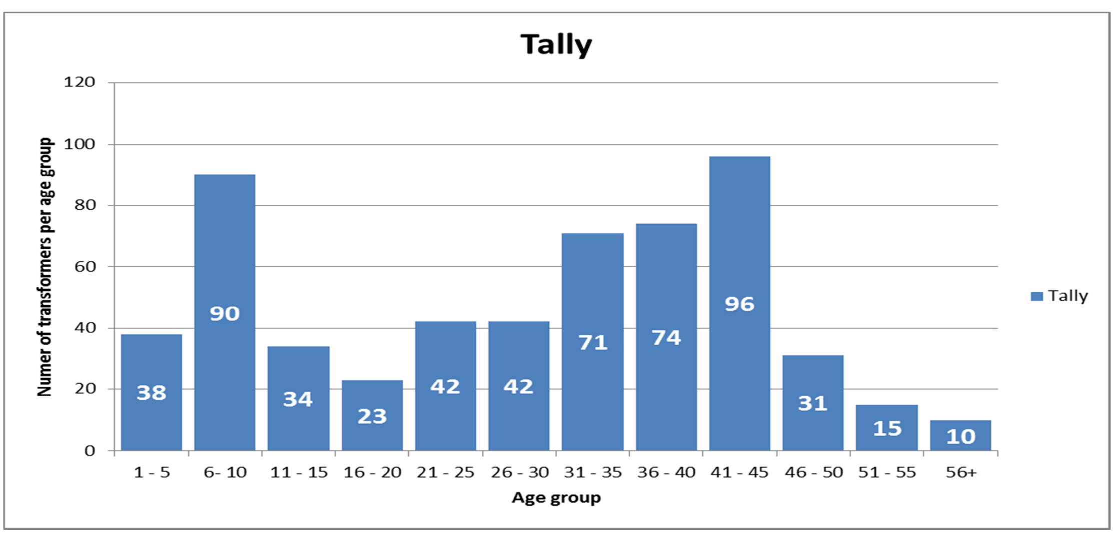

Figure 1: Eskom Transmission transformer fleet age profile

The average age of the fleet is expected to continue growing due to limited financial resources to execute replacements. This compels, in many cases, that a transformer be replaced only when it has failed. Coupled with the challenge of limited financial resources is the issue of skills. There is a limited ability to acquire young transformer engineers while most of the matured engineers are retiring or about to do so. The newly acquired manpower still requires time to develop and acquire the necessary experience. The combined effect of these issues compels Eskom to review its current approach on management of assets so that it can remain high performing company.

Furthermore, the Independent Power Producers (IPPs) have begun connecting to the Eskom Power Pool, and there are heavy penalties imposed to Eskom should its infrastructure not be available. It is therefore important that measures be put in place to ensure that transformer activities are optimized in order to reduce the probability of infrastructure unavailability.

The details for each of the strategies implemented and reflection on the objectives of each are discussed in the following sections.

2. OPTIMIZATION STRATEGIES

The optimization strategy, as it is going to be discussed in this section, includes technology employment, condition monitoring, maintenance, and asset replacement strategies. Each of these will be discussed on its own merit; however, they are greatly interlinked.

2.1. Technology Strategy

The four main objectives of the power transformers technology strategy are to make transformers last longer, safe to operate, cost effective, and visible to operators and asset life managers. Some technologies can be introduced as retrofits during the operational life of a transformer, however, some will need to be considered right from the design stage.

For power transformers and reactors, the following technology drives were put in place.

2.1.1. Vacuum type tap changers.

Transformer availability is important for any network, but more especially during the prevailing lack of redundancy in some critical circuits. The major need for an intrusive work, hence an outage, on a transformers is the tap changer maintenance. Traditional tap changers use oil as medium for arc-quenching during the tap changing activity. Since the arc-quenching takes place directly in the oil, the oil degrades, losing its electrical characteristics and compelling an intrusive intervention. Vacuum tap changer technology presents an advantage of reduced transformer maintenance requirements. This is because with this technology the arc-quenching takes place inside a vacuum chamber (bottle) and the oil is preserved. The oil replacement interval can be as long as the life time of a transformer in certain cases. This reduced maintenance frequency over a lifetime is critical when one considers that the tap changer maintenance skills are also scarce. All the above contribute towards a reduction in overall maintenance cost for the business, while it improves the asset availability.

Eskom is currently open to both the oil-type and the vacuum-type technology but with the majority of the appetite being on vacuum technology due to the known advantages. It is however still lesser than 10% of the fleet that is equipped with the vacuum type of tap changers. This percentage is expected to grow as more new transformers get commissioned.

2.1.2. Dry condenser bushings

The advantages of this technology are that it has relatively low maintenance requirements, no environmental risks, is durable, and fails safe. All these characteristics are important for a cost-effective life cycle management. For almost a decade Eskom is equipping new transformers and reactors with such a technology on bushings as far as the technology maturity allows. The strategy is to phase out all oil impregnated paper condenser bushing with dry type, especially the paperless type. The phasing out of oil impregnated paper bushings reduces the substation fire risk and in the future better insurance premiums can be negotiated.

2.1.3. Environmentally friendly oils

For the Eskom fleet, almost all of the liquid filled transformers and reactors are using mineral oil. While mineral oil has good insulation properties, it is non-biogradable. This poses a risk of contaminating the environment during handling and also in case of equipment failure. The regulations to handle mineral oil are becoming more and more complex and costly. Furthermore, there is a fire risk should a failure occur because its flash point is not that far higher compared to usual temperatures experienced during failures. This brings greater limitation on the application of mineral oil-filled transformers as far as urban substations are concerned. The introduction of environmentally friendly oils makes it possible to build compact substations while employing transformers of bigger power rating. The construction of the substations becomes more cost-effective because the passive and/or active firefighting infrastructure is eliminated.

The use of these ester oils further allows increased loading for a given power rating compared to the equivalent transformer filled with mineral oil. This means that, where it is possible, the power output of mineral oil insulated distribution transformer can be increased by using the ester oil. The economies of such an exercise will need to be verified first before they are implemented. Eskom’s strategy is to first employ these ester oils greatly on the distribution transformers (pole and ground mounted), while gradually escalating it to power transformer level.

2.1.4. Variable shunt reactors

Shunt reactors play an important role in the compensation of long and lightly loaded transmission lines. In order to achieve efficiency of the network, it is important to adequately compensate it. Some of the lines were originally adequately compensated but as the network is growing and getting interconnected, it is important to have the flexibility regarding compensation so as to achieve proper power transfer. Reactors in Eskom are traditionally of fixed inductance value, but now with the employment of tap changers, there will be a flexibility on inductance values, thus making it possible to precisely compensate a line.

2.1.5. Integrated condition monitoring

Condition monitoring has become an important aspect of today’s power network, especially at equipment level. Various technologies are being employed in order to get as much information as possible from the asset. The major setback has been to consolidate that information to have a holistic picture of the asset as this is currently manually done. The objectives of integrated condition monitoring are to make the equipment visible to the operators and asset life managers, to accelerate asset health index calculation, and to keep a dynamic asset heath index. This will be done by collating and consolidating all the information from the condition monitoring devices and make it available to the mentioned end users. This is demonstrated in in figure 3 of section 2.2 of this paper.

2.1.6. Low loss transformers

Efficiency is one of the major aspects of the smart grid, and the intention is to reduce power delivery losses. Loss evaluation is therefore part of the tender evaluation process for the power and the distribution transformers in order to encourage low loss transformers. For distribution transformers the amorphous core technology makes it possible to further reduce the losses. The production processes are however not yet aligned to such a technology in the local market. The Eskom strategy is not to dictate the material but use the loss evaluation as the leverage arm.

2.1.7. Thermally upgraded paper

Thermally upgraded paper is expected to prolong the life expectancy of transformers for a given loading factor. It further allows additional loading with less consequences compared to the normal Kraft paper as far as thermal degradation is concerned. For transformers that are loaded below nameplate rating for the majority of their life time, they can be expected to last much beyond 40 years, and this will lessen the replacement costs burden in the future. The application of the thermally upgraded paper further provides the flexibility of momentarily loading beyond nameplate, and this is important for a smart grid.

2.1.8. Fibre Optic enabled hot spot measurement

To optimally execute dynamic loading, especially beyond nameplate rating, and to more accurately determine the impact of the same, direct hot spot measurement is important. This technology is an added advantage in the visibility of the transformer as part of the substation visualization under the smart grid drive. Eskom is specifying fibre optic sensors on all major new power transformers and those undergoing repairs. Fibre optic temperature measurement (direct measurement) together with thermally upgraded paper provides better loading management.

2.1.9. Self-dehydrating breathers

The prevention of moisture ingress in a transformer is very important. The dehydrating breathers are employed for that purpose. It is however a fact that some of the transformers are in very remote substations and they do not get the attention they deserve for various reasons. The employment of self-dehydrating breather lessens the human dependence, while it provides critical information to the operator and end-user regarding the state of the breather itself. This forms part of substation visualization.

2.1.10. Online moisture removers

Not all moisture in a transformer can be addressed through the breathers. This is because the presence of some moisture is through the processes that bypass the breathers. Moisture from the leaks and the one resulting from the aging process cannot be addressed through the breathers. Online dryers are employed to remove such moisture. These also provide critical information to the operator about the equipment and provide input to automated asset health index score. Eskom's strategy is to employ this technology on units of 80MVA and above and with voltages of above 132kV or any special transformer that may be deemed critical.

2.2. Online Condition Monitoring and Control Strategy

As indicated before; the combination of the aging fleet, the scarce skills, and shortage of funding for the desired replacements; makes condition monitoring an important aspect of asset management. Most power transformers will have to be operated beyond the traditionally expected life span. In order to reduce unexpected failures, Eskom has to know the current status of every critical transformer. If the health status is known, the fleet can be better managed by implementing corrective measures on time and then preparing for quick recovery where failures can no longer be avoided. On the other hand, these signals can be utilized as inputs to the substation visualization for smart substation.

Eskom transformer engineers are continually working on both the condition monitoring strategy and philosophy. The ideal online condition monitoring of power transformers and reactors includes the following:

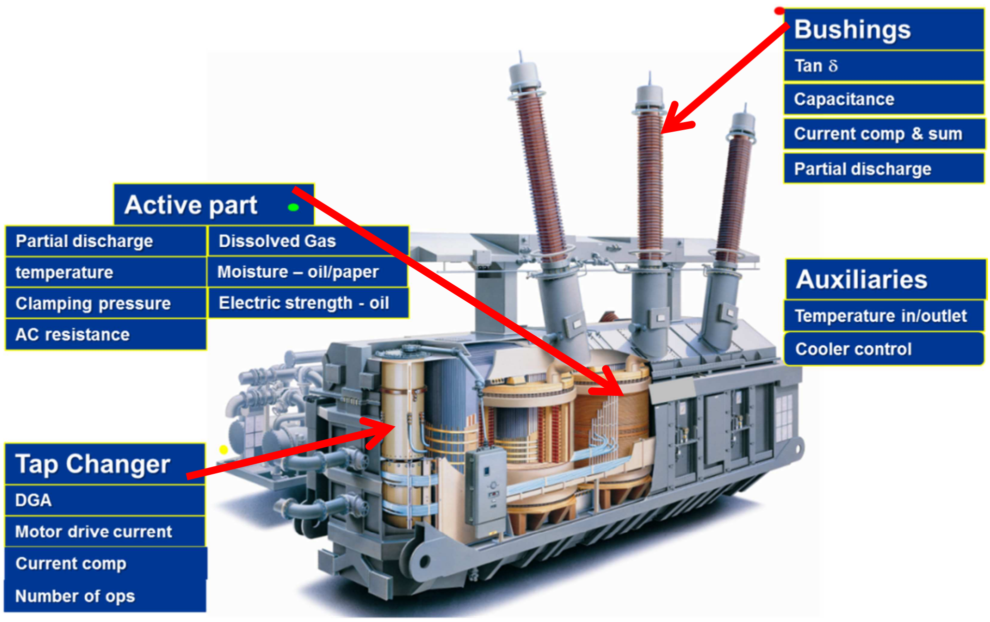

Figure 2: Illustration of ideal transformer online condition monitoring

2.2.1. Active Part

The purpose is to access and assess all the critical information about the active part and it includes both the winding and the core information. The dissolved gas analysis (DGA), the partial discharge (PD), and the AC resistance will provide the status of the unit and for which they may be limited ability to correct. The dissolved gasses are measured using online gas analysers, PD is detected through a sensor mounted somewhere inside the tank, and the AC resistance on the terminals. The latter two are not yet implemented, while the research is being finalized. The moisture, the electric strength, and the temperature will indicate the 'care' condition, which can be rectified. There is no known method at this stage to measure the residual clamping pressure on the windings and therefore this will still remain at a dreamland.

2.2.2. Tap Changer

The tap changer is the major reason for transformer intrusive maintenance. It is desired to change from time or duty based maintenance to condition based one as will be discussed later. To achieve this, more information has to be extracted from the tap changer. Currently only moisture and electric strength are being monitored, offline. Online condition monitoring is being introduced to look at all the critical parameters of the tap changer and using this information to plan an outage. The DGA interpretation will however not be the same for vacuum type and oil type. Vacuum type will be monitored as the main active part oil, while for oil type high levels of gasses are expected. The motor drive current or current comparison will be an indication of certain mechanical defects or degradation.

The number of operations will be used to alert the need of doing a detailed study on that particular tap changer once it has reached a specific duty.

2.2.3. Bushings

Bushing failures are major causes of transformer fires and it is important that they are closely monitored. The recent dry technology offers a more reliable product however online condition monitoring is still important to better determine the dynamic health status of a transformer. For bushings the PD, tan delta, and capacitance are measured from the tests tap. The temperature measurement on the pin-clamp interface can be achieved by using thermal image camera.

2.2.4. Controllability

In addition to visualization, it is a desire to be able to have some controlling ability on certain plants. This can be done through the intelligence circuit of a certain component, by remote operation or both. The example of such requirements is on fans and pumps, which will allow the starting of a standby unit if one of the base ones were to fail and also to balance the duty of the same items.

Collectively, these will all play major roles in successfully implementing the condition based maintenance. The framework of the integrated condition monitoring can be summarized as below

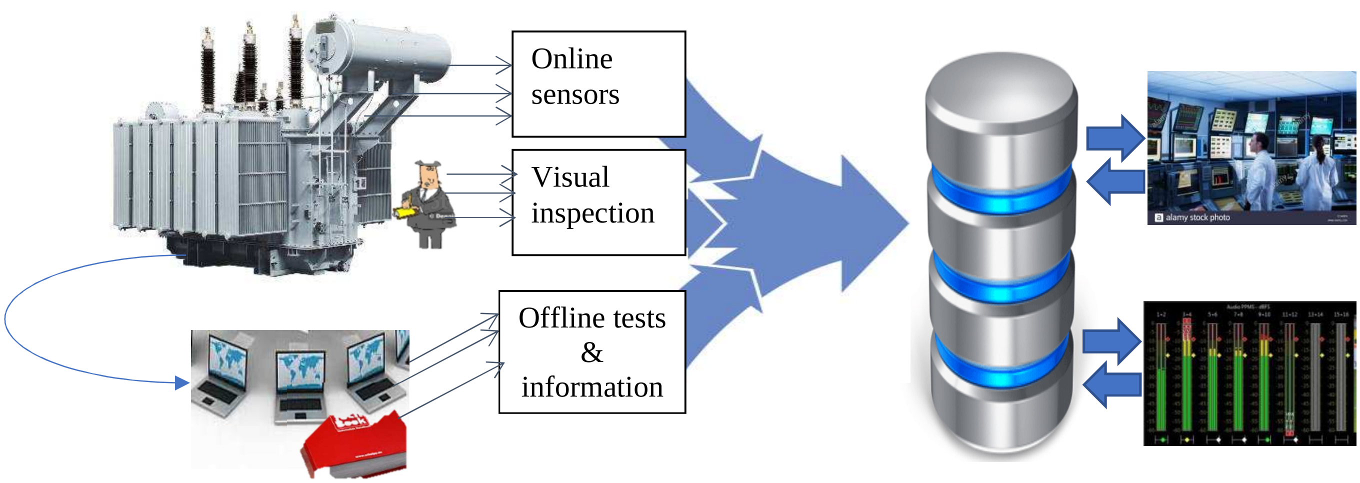

Figure 3: Integrated condition monitoring framework

2.3. Maintenance Strategy

Concerning maintenance, the ISO 55000 stipulates both over maintenance and under maintenance are inadequate for effective asset management. One of the key strategies for the developing economies is to be cost effective on maintenance as well. The transformer maintenance in Eskom has mainly been based on duty or time. This is however being changed due to cost-effectiveness drives that the business is implementing. Time or duty based maintenance may in certain circumstances result in over-expenditure with regards to maintenance, yet the consequences of corrective maintenance may also exceed those of former ones.

Condition based maintenance may fit in the middle point between those two; however, it requires accurate measurement and sufficient information or data to be available. It is to be noted that to optimize on maintenance spending does not necessarily start with condition monitoring, it starts right at the equipment specification phase. The selected components and materials should be those that promote less maintenance requirements. The traditional major maintenance interval in Eskom has been around 3 to 7 years for large power transformers. It is desired to extend this. For the transformers employed in the Generation business, this was synchronized with other major plant outages and for those in the Transmission network; it was with major overhaul of breakers.

The approach to reduce maintenance spending in Eskom is therefore coming in two ways, one is with the specified technologies and the other is converting from preventative maintenance to condition based maintenance. From the technology and design point of view, these are some of the considerations.

2.3.1. Tap changers

The main reason for transformer maintenance is the tap changer and the oil in certain cases. The oil-type tap changers have demanding maintenance requirements due to the degradation of the oil during tap changing. The introduction of the vacuum tap changers is however becoming a game changer. Studies have shown that in most cases for Eskom transformers, the vacuum tap changer technology will totally eliminate the need for intrusive tap changer maintenance in life span of 40 to 50 years for a transformer.

2.3.2. Insulation system preservation systems

This refers to technology employed to preserve either the solid insulation, oil, or both. It includes self-dehydrating breathers, air cells, and online dryers. When moisture and oxidation are adrequately managed, the maintenance can be further delayed or prevented.

2.3.3. Partial drain requirements and gasketted interfaces

In some cases the intrusive work cannot be avoided, it is important to optimize the scope and the time to execute such maintenance. One of the time consuming processes during a transformer intrusive work is the oil-filling process, which can be a period of 7 – 9 days for a large power transformer. Any design considerations like avoiding gasketted interfaces at the lower part of the tank and selecting proper bushings connection type can reduce the requirements by simplifying the oil filling process during minor activies e.g. replacing a pressure relief device.

2.4. Asset Replacement strategy

It is desired to proactively replace old assets before they can fail since it is only a thin line that separates replacing what is still useful and operating that which is dead. In the present environment, there are limited funds available to execute such replacements, and the assets are therefore bound to operate beyond the expected life. It can be admitted that this expected life is greatly put on the chronological age. Smarter ways are now to know how to quantify the remaining life or lost life of an asset and replace it at that magical moment. It is unlikely to catch such a moment but it can be done with much less error.
The Eskom strategy for transformers and reactors is to do periodical appraisals in order to identify high risk units and then distribute the available funds first to the critical ones. The main challenge at this stage is that the asset health calculation is very static. It is to be noted that it takes years from the time the asset is identified as a high risk to the time of replacement. There are also many dynamic parameters in the risk determination equation. Through condition monitoring strategy and

the substation visualization this can be improved in order to allow the business to be more cost-effective.

3. CONCLUSIONS

Technology and innovation driven solutions are available for power transformers and reactors, and they can assist all transformer-end users to be more cost-effective. This is important for the developing economies so that the channelling of the limited funds can go a long way. The capital investment required for these technologies might be huge; however, the return on investment can be easily realized. The possible benefits cover many aspects of the business and make it possible to do things in a new way.

Substation visualization is becoming an important feature for a network to remain reliable and sustainable. Installation of the available sensor technologies will improve asset management by reducing the human factor and speeding up the information processing time, thereby enabling asset managers to implement corrective meausres on time.

When these technologies are well considered at the specification phase of transformers and reactors, a positive impact on maintenance requirements can be achieved.

Together, all these make transformers an important feature of smart grid.

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